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With the Report of a Case in which the Sciatics of a Dog were Transplanted Successfully Between the Severed Ends of the Median and Ulnar Nerves of a Man.

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PERIPHERAL NERVE TRANSPLANTATION,

WITH THE REPORT OF A CASE IN WHICH THE SCIATICS OF A DOG WERE TRANSPLANTED SUCCESSFULLY BETWEEN THE SEVERED ENDS OF THE MEDIAN AND ULNAR NERVES OF A MAN.*

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The operation of implanting between the resected ends of a peripheral nerve a segment of a nerve from a recently amputated limb or from one of the lower animals is comparatively rare. In the majority of cases of accidental impairment of the conductivity of a peripheral nerve the proximal and distal fragments can be brought together and directly sutured. Obviously this is the ideal method, and that, oftentimes, it is markedly successful may be seen from the reported cases of apparent primary union occurring after immediate suturing of the divided nerves.

In a certain proportion of cases, however, so much of the nerve-substance will be removed as to preclude all chance of a direct union of the divided ends of the nerve-trunk. This will happen more often during the removal of tumors involving a peripheral nerve. The same condition may result from an extensive crush of the nerve-substance, necessitating the resection of considerable portions of the nerve before healthy tissue is reached, or the injured nerve may be so embedded in dense connective tissue as to render a dissection at the point of the lesion exceedingly difficult and of doubtful utility.

Under these conditions the surgeon must decide what method of bridging over the gap in the nerve-trunk and restoring its conductivity shall be employed. His choice will naturally depend largely upon the recorded results of other operators, including experimental as well as actual work on the human subject. Deductions from the cases of nerve transplantation will be rendered difficult from the small number recorded, from the meagreness of the reports and the absence of the very details needful to the settling of certain mooted questions.

* Inaugural thesis read before the Chicago Academy of Medicine, May 13, 1898.

To observe, treat, and record intelligently a case of nerve section requires a knowledge of nerve physiology and histology rarely possessed by the average surgeon. It is only by the combined efforts of specialists in these departments that such cases of nerve surgery can be worked out to the greatest advantage.

If the present paper shall prove to be of any scientific value I feel that it will be due largely to the assistance of my friend, Professor G. Carl Huber, of the University of Michigan, whose splendid work on nerve degeneration and regeneration is so well known.

History of the Case. The patient, the report of whose case forms the basis of the present article, was referred to me by his brother, Dr. A. G. Graybill, of Caledonia, Mich., to whom I am indebted for accurate notes taken from time to time at my request.

N. G., male, aged twenty-four years, on May 17, 1896, sustained a severe injury to the right wrist by coming in contact with a circular saw, the cut extending transversely across the wrist and nearly to the bone. The ulnar artery and a number of the flexor tendons were severed and immediately sutured by the local surgeon, who assured the patient that the nerves were uninjured and that in time he would regain full use of his hand. The wound was dressed ten days after the operation and found to be suppurating. For a time the wound was dressed every day, and up to the time of consulting his brother, some four months after the injury, had not healed. The patient had no feeling in the hand, and at first complete loss of muscular movement. After awhile he was able to close his hand, but not well. Sensation did not improve, and his fingers began to draw upward, and he was unable to straighten them. Finally sores began to appear upon the fingers, and becoming alarmed he travelled many miles in order to place himself under his brother's care.

My first examination of the case was on September 21, 1896. The patient was a remarkedly well-developed and muscular man. About 7 cm. above the right wrist was situated an irregular cicatrix. On the ulnar side of the forearm it was depressed and adherent. There was a longitudinal cicatrix on the ulnar side of the forearm, extending from 2 cm. above the depressed cicatrix to the wrist. About 3 cm. above the wrist, over the normal site of the median nerve, was a superficial sinus, from which a small quantity of pus could be pressed. The flexor tendons were contracted and bound down by cicatricial tissue. (Figs. 1 and 2.) Accompanying this contraction was a flexure of the fingers which could not be overcome by passive motion.

The trophic changes in the hand were marked. It was distinctly colder than the left, its color dull red, surface smooth and glossy, and nails corrugated. There were a number of blebs the size of a pea scattered over the dorsal surface of the third and fourth fingers. A superficial ulcer, 1½ cm. in diameter, existed at the root of the nail of the third finger. (Fig. 1.) There was a marked atrophy of the small muscles of the hand, and the thenar and hypothenar eminences were considerably flattened. The interosseous spaces were also markedly furrowed. The hand could be closed only partially, there being inability to bring the finger-tips into the palm. Abduction and apposition of the thumb were impossible, an object in the hand being

grasped only through the agency of the long flexors. Extension of the fingers was rendered doubly impossible by contraction of the flexor tendons and atrophy of the interosseous and lumbricales muscles.

FIG. 1.

Showing trophic changes. Taken four days prior to operation.

The area of anæsthesia was tested by the induced current and by a pin-prick. There was absolute anæsthesia in the palmar surface of the hand, over all the digits and inner surface of the thumb. The ulnar side of the hand was anæsthetic. On the dorsal surface the skin was anæsthetic over the entire distal half of the first three digits, over the ulnar half of the proximal part of the third digit, and over the entire surface of the small digit and a corresponding area downward to the wrist. There was a small border of anæsthesia on the radial side of the proximal half of the first finger and the outer surface of the thumb. (Figs. 3 and 4.)

The patient was directed to return home and have the suppurating tract treated daily with peroxide of hydrogen until it was entirely healed, as it was considered useless to attempt anything operative upon the severed nerves save in a clean field. On October 17th, the wound having healed entirely, he was seen in consultation by Professors Herd-

man and Huber, of Ann Arbor. The former kindly subjected the hand to a very careful electrical examination, as follows: Examination with Waite & Bartlette high-tension induction coil, secondary in use, four interruptions per second, with secondary coil, carrying the primary to the extent of 25 millimetres. With a flat electrode one and a half inches in diameter at the back of the neck, and a pointed electrode over the nerves at the elbow-joint, responses were obtained from the left ulnar and median nerves. With electrodes in the corresponding position on the right arm it was necessary to move the secondary

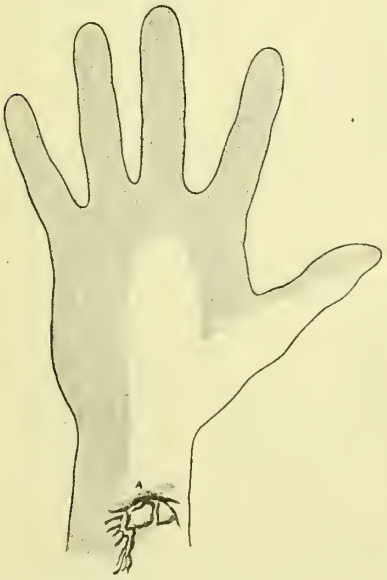
FIG. 2.

Taken two and a half months after operation.

coil from 25 to 33 millimetres to obtain some response. With pointed electrodes on the nerves and muscles in the palm there was no response. The anæsthetic area was carefully noted by the induced current, and corresponds to that noted in Figs. 3 and 4. *Continuous current examination.* In muscles supplied by the median, a current of ten milliampères being used, the response was sluggish and wormlike. A. C. C. greater than C. C. C. The same condition existed for the muscles supplied by the ulnar. Reaction of degeneration, therefore, was shown to be present in the hand-muscles supplied by these two nerves.

Operation, October 24, 1896, five months after the injury. At the time of the operation the trophic changes on the fingers were still marked, and rendered complete asepsis of the wrist somewhat difficult. The fingers were wrapped in iodoform gauze and cotton, but the wrappings became deranged at the time of the operation, and possibly accounted for the superficial suppuration of the wound over the median nerve.

FIG. 3.



Right hand, palmar surface, October 17. Anæsthetic area shaded. A. Location of scar.

FIG. 4.

Dorsal surface, October 17.

The hand was rendered bloodless by an Esmarch bandage, and an incision 7 cm. long was made over the normal site of the median nerve. (Fig. 2.) The flexor tendons were found to be very adherent and contracted. The cut median was located after a little searching. It was considerably thicker than the normal nerve, and its two ends were united by a small band of dense connective tissue. (Fig. 9.) The proximal end of the median ended in a hard bulb 2½ cm. in length and 2 cm. in width. In order to expose the nerve-tissue at the proximal and distal ends, and to get rid of all connective tissue, the bulb above and a portion of the nerve below were removed, the whole fragment, including the connective-tissue bridge, measuring 3½ cm. So much force was required to bring together the cut ends that it was decided best to fill in the gap with a dog's nerve.

A young black hound had been aseptically prepared, and 4 cm. of the right sciatic were removed and sutured between the resected ends of the median with kangaroo tendon. A fine curved needle was used, and two sutures passed ½ cm. away from the ends and carefully tied. The fascia was sutured over the transplanted fragment, and the flexor tendons loosened as much as possible. The skin was sutured with catgut, a few strands of silkworm-gut being used for drainage. An incision 7

cm. long was now made over the normal site of the ulnar nerve. Considerable difficulty was experienced in locating the incised nerve, from the fact that the upper fragment was joined to the distal fragment of the severed carpi ulnaris tendon. The distal end of the ulnar nerve was found lying slightly below and interior to the proximal end. The two ends were trimmed as in the case of the median, and 4 cm. of the left sciatic of the dog transplanted between the ends, as previously described. The fascia was sutured over the fragment with catgut and the incision closed in the same manner as was that of the median. A plain sterilized dressing was placed over the wounds and arm, and the hand placed in a posterior splint, the fingers being extended as much as possible and held in place by a bandage.

The day following the operation there was considerable oozing, and the dressings were changed, affording an opportunity of testing the anæsthetic area on the thumb. The other fingers, being bandaged and forcibly extended upon the splint, were not disturbed, and therefore their sensory areas were not tested. The test on the thumb was made with the point of a pin, the patient's eyes being closed. Comparison with the anæsthetic area, indicated in Fig 3, according to tests made before the operation, showed a distinct return of the sensation over the palmar side of the thumb to the distal end of the first phalanx.

Three days after the operation the patient left the hospital and returned to Caledonia, where he was under the constant medical supervision of his brother, who made frequent and accurate notes of his condition. The wound was dressed for the second time on October 27th, and two days later a third time, when the median wound showed signs of superficial suppuration, although the temperature was normal, and so remained.

October 31*st*, seven days after operation, fourth dressing, ulnar wound healing by first intention. Several stitches over the median have given way. Considerable oozing from the line of incision. Splint omitted and fingers forcibly extended without much difficulty or pain. Sensation: Detects the prick of a pin over the palmar surface of the thumb as far forward as the second phalanx. Slight irritation of this area produces prickling sensation of the hand, extending up the hand and wrist to the wound.

November 1*st*. Detects the prick of a pin on the first finger, dorsal surface, to the root of the nail, and over the dorsal surface of the second finger to the middle of the second phalanx.

2*d*. Ulnar incision healed by first intention. Slight superficial suppuration in the median incision. Detects the prick of a pin over the entire dorsal surface of the third phalanx of the second finger.

4*th*. Detects prick of pin or pencil over the dorsal surface, palmar side, of the hand to the end of the second phalanx of little finger, and previously anæsthetic area of the ulnar side of the third finger to the end of the second phalanx. The hand is much warmer than before the operation.

6*th*. Sensation over the whole of the dorsal surface of the thumb to the nail on the palmar surface, and on both sides of the thumb sensation exists to within 2 cm. of the end of the thumb. Sensation over the dorsal surface of the first finger to the nail and on the sides and palmar surface to the end of the first phalanx. Sensation on the dorsal surface of the second finger and the ulnar side of the second

finger to the end of the third phalanx. Over the corresponding area on the palmar surface of the same finger a pin-prick could be detected to the end of the second phalanx. There was no sensation on the ulnar side of the palmar surface of the finger. In the third finger sensation was good on the dorsal end of the first phalanx. On the dorsal surface toward the second finger there was partial sensation to the end of the second phalanx; sensory area of the dorsal surface of the little finger extended to the end of the second phalanx. No difference is to be noticed in sensation when a pin, pencil, or electrical current is used. Anæsthetic areas of the hand are colder than the sensory areas. No response of the muscles to the faradic current.

8th. Area in the palm of the hand which was distinctly sensitive to a pin-prick at a previous examination is anæsthetic to-day.

9th. Hand has a natural color on the dorsal surface, with the exception of the third phalanx of the second, third, and fourth fingers. Can almost completely extend the first finger. The ulcers have healed. There is a decided improvement in the muscular power of the hand. Can touch the dorsal surface of the second knuckle of the first finger with the end of the thumb. Can approximate the thumb to the end of the second finger easily, and to the third finger with some difficulty. These movements were hitherto impossible. Can abduct the thumb more daily. Can hold a tin wash-basin between the thumb and forefinger, while before the operation it was impossible to hold as light an object as a lead-pencil. Can detect degrees of heat and cold with the dorsal surface of the hand, a match flame being felt at a distance of two inches and heat from a stove at six inches.

The hand was treated daily with massage and electricity, and improvement in sensation and motion was very satisfactory. The changes in sensation have been noted on the charts.

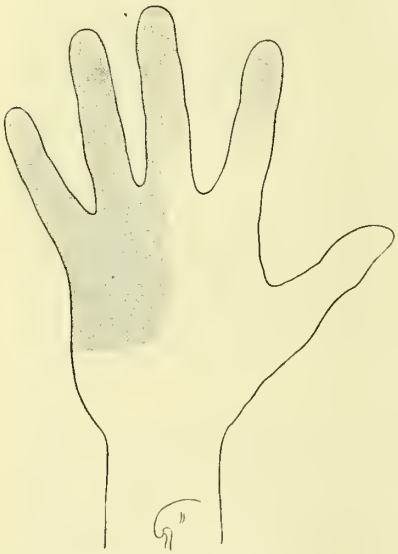
December 31, 1896. There is a blister 1 cm. in diameter, and another one-quarter as large, on the palmer surface of the third phalanx of the first finger. The skin of the entire hand has lost its shiny look, and appears quite normal. The fingers have lost their puffy look. The nails are growing out and the ridges are disappearing. The improvement in the muscular power is very marked. The tips of the fingers can be closed into the palm. Opposition and adduction of the thumb improving, although addnction is impossible without flexion of the thumb. Can hold a pencil between the thumb and fingers so tightly as to require considerable force to withdraw it from his hand. The first finger can be nearly fully extended; the others are held by the contracted flexor tendons. There is still atrophy of the interossei and the muscles of the thenar and hypothenar eminences, although these depressions are much shallower than before the operation.

Patient left Caledonia for Canada, January 28, 1897. He was satisfied that he could earn his living by manual labor, and, with the exception of the contraction of his fingers, claimed his hand was as good as ever. His grip was strong, and he could perform such tasks as chopping wood. Sensation was complete over the entire dorsal surface of the hand excepting over the third phalanges of the second, third, and fourth fingers. The only remaining anæsthetic areas of the palmar side of the hand were over the second and third phalanges of the third and fourth fingers and the third phalanx of the second finger.

He went to work in the saw-mill, and some time in Febrnary, 1897,

unfortunately froze the right hand. He persisted in working, however, and one week later again froze the hand, this time so badly that the swelling extended half-way to the shoulder. Five months later the hand had practically returned to its condition at the time of the frostbite, with the exception of the extremities of the first and third fingers, where there were sinuses continually discharging pus. There was also loss of sensation over the last phalanx of the first finger, although this area had become sensory after the operation. Eight months after the frostbite the distal phalanx of the first finger was amputated and also the second and third phalanges of the third finger, the amputation wounds healing well.

FIG. 5.



Palmar surface, November 8.

FIG. 6.

Dorsal surface, November 8.

The condition of the hand on January 1, 1898, was as follows: Sensation is complete in the hand, except a small area between the last joint and the nail on the dorsal surface of the second and little fingers. The palmar surface of the hand and fingers is sensitive to the slightest touch with a feather. Sensation of heat and cold as good as ever. Some atrophy of interossei and muscles making up the thenar and hypothenar eminences. Motion of the hand good and strong. From lack of exercise of the hand resulting from frostbite there was increased contraction of the flexor tendons, especially those of the little finger. Cannot adduct or abduct the thumb; neither can the fingers be separated or brought together.

Under date of April 21, 1898, the patient writes: "My hand is good and strong, but my second finger is bothering me the same as the other two did. The hand is not filling out between the fingers. Sensation is good in the whole hand and fingers, except the dorsal surface of the second finger to the first joint. The end of the finger continues sore,

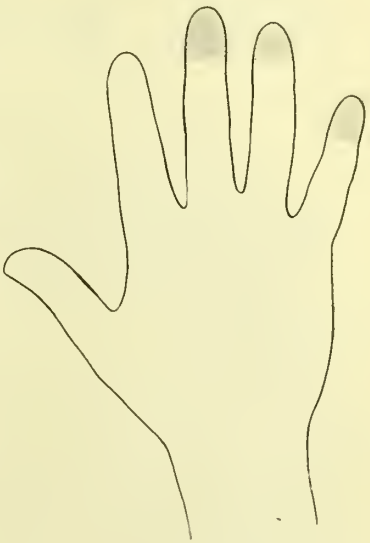
and may have to have it amputated as far as the first joint. I am hard at work every day."

Fig. 1 was taken before and Fig. 2 after the operation. The changes in sensation have been outlined in Figs. 3 to 8. Sensation was tested by means of a pin-prick. Careful comparison of the notes of change of sensation after the operation and the charted areas will show variations of the sensory areas, a part sensory at one time becoming anæsthetic at a subsequent date. This "vacillating sensation" will be considered later on.

FIG. 7.

Palmar surface, December 31.

FIG. 8.

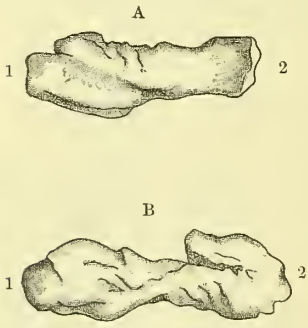


Dorsal surface, December 31.

Microscopical Examination by Dr. G. Carl Huber of Segments of the Median and Ulnar Nerves Removed at the Time of the Operation. The segments removed from the median and ulnar nerve at the time of the operation (the size and shape of which may be ascertained in Fig. 9) were sent me in Müller's fluid. After thorough hardening in this solution and dehydration in alcohol the tissues were prepared for paraffin embedding by cutting them into several smaller pieces. The manner of their subdivision may perhaps be shown best by means of the accompanying Fig. 10, where *c* and *p*, respectively, are used to designate the central and peripheral end of *Med* (median segment) and *Ul* (ulnar segment); *nb*, the nerve-bulbs of median and ulnar central ends; *pm*, peripheral median, and *t*, a portion of the forearm tendon to which the ulnar was attached; *e*, a connective-tissue bundle uniting the bulbs on the peripheral end of the central median stump (*nb* in *Med* of figure) to the central end of peripheral median (*pm*, of figure), and the bulbs on the peripheral end of the central ulnar (*nb* in *Ul* of figure) to the tendon. The lines in Fig. 10 indicate the position and directions of the sections by means of which the segment removed from the median nerve was divided into five smaller pieces, the segment from

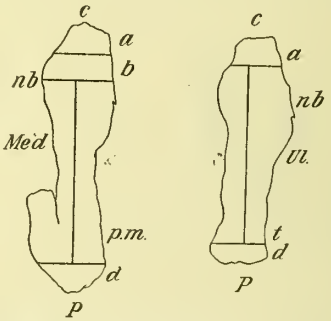
the ulnar into four pieces. The pieces thus obtained were embedded in paraffin and sectioned, the sections varying from 8 to 15 μ. in thickness. It may readily be seen that in this way cross-sections of the central end of the median and ulnar segment, as also cross-sections of the peripheral median and the tendon attached to the ulnar (*a*, *b*, and *d*, of Fig. 10), and longitudinal section of the tissue between these respective cross-sections were obtained.

FIG. 9



A. Ulnar nerve. 1. Proximal end; 2, tendon. B. Median nerve. 1. Proximal end; 2, distal end.

FIG. 10.



Median and ulnar segments, showing division into smaller pieces, as mentioned in the text.

The sections thus obtained were fixed to cover-glasses, the paraffin removed, and representative sections from each of the several pieces, obtained as above described, were stained after the following methods:

1. Hæmatoxylin, counter-stained with eosin.
2. Hæmatoxylin, counter-stained with picric-fuchsin.
3. Stroebe's anilin-blue-saffranin method for bringing to view the axis cylinders. For some unexplainable reason the sections stained in this way did not show with the usual clearness the axis-cylinder differentiation; with care, however, they could be distinguished from the surrounding tissue when the oil immersion was employed.
4. Weigert's hæmatoxylin stain as modified by Benda. It was found that this method could be used on sections cut in paraffin, the myelin staining in the well-known blue-black color. The paraffin sections, after fixation to the cover-glasses and removal of the paraffin, were placed from four to five days in Müller's fluid; were then impregnated with the iron salt (liq. ferri tersulphatis one part, to two parts of distilled water) for twenty-four hours, stained in 1 per cent. aqueous solution of hæmatoxylin for forty-eight hours, bleached in a $\frac{1}{4}$ per cent. solution of permanganate of potassium, and finally in a 10 per cent. solution of hydric sulphite, washed in water, dehydrated, cleared in xylol, and mounted in balsam. By the use of these several staining methods the general structure of the tissues was studied to some extent, and the development of new axis-cylinders and the myelation of the new fibres and the myelin of the old fibres were brought to view.

Microscopical Appearance of Sections made from the Segment Removed from the Median.

Cross-sections of the central portion of the median segment (*a*, of Fig. 10) show in all essentials the structure of a normal nerve-trunk, with this

exception—the nerve funiculi are separated by a larger amount and by a more dense fibrous tissue—epineurium—than is the case in a normal nerve-trunk. The nerve-fibres in the funiculi present nothing worthy of special mention, showing in all essentials the structure of a normal nerve-fibre. Cross-section through the bulk of the central median (*b*, of Fig. 10) present, however, an entirely different appearance. One such section is reproduced in Fig. 11. As may be seen from this figure, one

FIG. 11.

Cross-section of bulb on the peripheral end of the central median stump. Magnified twenty times; reduced about one-half. *a*. Normal nerve funiculi. *b*. Bulb-tissue. *c*. Nerve funiculi consisting of new nerve-fibres cut obliquely.

side of the section showed a number of normal nerve funiculi (*a*), each surrounded by epineurial sheath and separated by a rather dense epineurium. The greater portion of the section presents, however, a very characteristic structure—one which may be referred to as the structure of a nerve-bulb. In its most characteristic appearance (see *b*, of Fig. 11, and more highly magnified in Fig. 12) it presents a loose areolar connective tissue, in the meshes of which are seen small nerve-bundles, consisting of from two to ten and now and then as many as

sixteen to eighteen small nerve-fibres, which have a more or less irregular wavy, tortuous, or spiral course, the individual nerve-fibres in these small bundles being often separated by a few connective-tissue fibres.

These small fibres consist of an axis-cylinder, and the majority of them have a very thin layer of myelin, and are beset with numerous nuclei; in short, they present the appearances of newly formed medullated fibres.

Fig. 12.

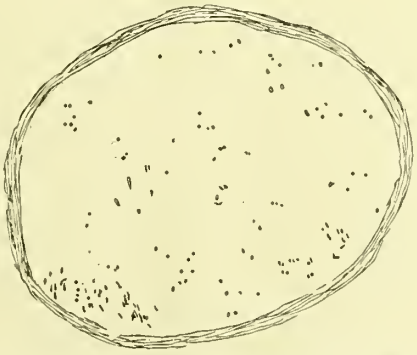
Bulb-tissue magnified about 900 diameters.

In a section passing through a funiculus of the nerve-trunk, central to the bulb, it may be seen that in that portion of the nerve funiculus which did not undergo degeneration the nerve-fibres are parallel and present essentially the structure of normal nerve-fibres. On reaching the beginning of the bulb-tissue the nerve-fibres assume the character of newly formed nerve-fibres (very small nerve-fibres, with only a thin layer of myelin and many nuclei); at the same time these smaller fibres begin to spread out fan-shaped, and sooner or later break up into small bundles, which are no longer parallel, but may be seen twining their way between the connective-tissue bundles of the bulb. Oftentimes large bundles are deflected from their course, as may be seen in the cross-section presented in Fig. 11, where at *c* such bundles are cut obliquely and longitudinally.

Peripheral Median. Cross-sections of the central end of the peripheral median present the following appearances: The nerve funiculi are separated by a relatively large amount of fibrous connective tissue which is much denser than the epineurium of a normal nerve-trunk. In preparations stained with hæmatoxylin and eosin or picric fuchsin all the nerve-fibres constituting these funiculi present the appearances of completely degenerated nerve-fibres — that is to say, collapsed sheaths of Schwann containing a small amount of the nucleated protoplasm. When, however, such cross-sections are stained in Weigert's hæmatoxylin it may be seen that here and there among the degenerated fibres some regenerated fibres, with a very thin sheath of myelin, are to be found. I have represented in Fig. 13 a nerve funiculus sketch from a cross-section of the peripheral median stained in Weigert's

hæmatoxylin. In this figure only the medullated nerves are regenerated. The sketch was made with the aid of the camera lucida, and shows not only the number and arrangement of these small, medullated fibres, but also shows that while many are cut crosswise, others are cut obliquely, showing that some of these regenerated fibres in the peripheral median have an irregular course and are winding their way along paths of least resistance. In cross-sections of the peripheral median stained after the Stroebe method, here and there a small axis-cylinder may be made out. These sections show, therefore, that in the peripheral median a certain number of regenerated fibres are to be found among the completely degenerated nerve-fibres.

Fig. 13.



Cross-section of a funiculis of the peripheral median, stained in Weigert's hæmatoxylin. Only the medullated fibres are shown. Magnified about 250 diameters.

Longitudinal sections of the median segment (made as above described) present appearances worthy of more especial consideration. Reference has above been made to the structure of the peripheral and of the central median, namely, the nerve-bulb, consisting of newly formed nerve-fibres, many of which had a thin sheath of myelin grouped into small bundles and separated by an areolar connective tissue. Between this nerve-bulb and the peripheral median there is found a dense fibrous tissue (*c*, in Fig. 10). Into this connective tissue could be traced from the nerve-bulb small medullated nerve-fibres, well shown in Weigert's stained sections. They were found here and there in this tissue, either as single fibres or as small bundles of fibres, which could be traced into the peripheral median stump; and, while it was not possible in any one longitudinal section to trace a single newly formed medullated fibre, or a small bundle of such fibres, from the nerve-bulb on the peripheral end of the central median stump through the connective tissue intervening between it and the central end of the peripheral median and into the peripheral median, owing to the fact that these small medullated fibres do not follow a straight course, because they are compelled to wind their way through the organizing connective tissue, taking in this paths of least resistance between connective-tissue bundles, this would not go to show that the fibres found in the peripheral median did not grow into it from the central stump. Their arrangement in these longitudinal sections suggests this down-

growth very strongly, and may be interpreted as showing that some of the budding axis-cylinder proeesses of the central end had developed far enough toward the peripheral median to be able to grow through the connective tissue forming between the central and peripheral portion of the divided median, and thus reaeh the peripheral median. How far down in the peripheral median sueh fibres had grown at the time of the operation can only be eonjeetured.

Ulnar. The study of the segment removed from the ulnar loses in interest owing to the fact that the eentral end of the peripheral ulnar was lost at the time of the operation. As has been previously stated, the peripheral end of the eentral ulnar segment was, at the time of the operation, found united to one of the forearm tendons, to whieh it seems to have been sutured at the time of the injury. The segment of the ulnar sent me for examination eonsisted, therefore, of the peripheral portion of the eentral ulnar stump, firmly united by fibrous tissue to a short segment of tendon. Cross-sections of the eentral end of the ulnar segment (*a*, of Fig. 10) presented appearances very similar to that deseribed for the eentral median segment and shown in Fig. 11, and need, therefore, no further description. Cross-section of the peripheral portion of the segment removed from the ulnar (*c*, of. Fig. 10) shows, for reasons above given, the structure of the tendon. Longitudinal seetions of the ulnar segment (along the line shown in Fig. 10) show the ulnar ending in a large nerve-bulb, whieh was intimately united to the tendon by means of fibrous tissue. In none of these sections was I able to trace any newly formed nerve-fibres beyond the nerve-bulb, the dense strueture of the tendon to which the ulnar was probably sutured at the time of the injury preventing the downgrowth of the axis-cylinders from the central ulnar stump.

Microscopical Examination of Amputated Fingers (by Dr. G. Carl Huber). The tips of the two fingers, the third phalanx of the first finger, and the seeond and third phalanges of the third finger were sent me in aleohol. Pieces from various places in the amputated fingers were embedded in paraffin, seetioned, and the sections fixed to eover-glasses and stained in hæmatoxylin and eosin-hæmatoxylin and Van Giesen's pieric aeid, aeid fuehsin solution, hæmatoxylin, and orange G. Attempt was also made to stain them after Weigert's hæmatoxylin method and some of the methods for differentiating the axis-cylinders in the nerve-fibres; but, owing to the fact that the tissues were hardened in alcohol and not in a chrome salt, these latter methods did not prove satisfactory.

In seetions prepared after the above methods it may be seen that the tissues other than the nerve-fibres and end-organs to be mentioned, present, as far as may be determined, a normal structure. Epidermis and sweat-glands are all normal, as is also the dermis. Yellow elastie tissue, as shown by the orcein method, is normal in amount and distribution. The great majority of the vessels present no deviation from the normal structure, with the exception of one of the digital arteries found in the volar side of the third finger. This vessel, as seen in cross-seetion, presents on one side a very much thickened subendothelial coat. The nerve-trunks, both palmar and dorsal, as also the smaller branches here and there met with, present at first sight the appearance of completely degenerated nerves. The epineurial tissue is thieker and denser than in a normal nerve of the same size. The same is true of the perineurium surrounding the several funieuli. The strueture of the nerve-

fibres is most clearly seen in a number of small branches cut obliquely in for a short distance longitudinally. In these sections it may be seen that such degenerated fibres consist of a very small amount of homogeneous protoplasm in the form of a thread or very delicate band surrounded by a very delicate sheath. In the course of these fibres, rod-shaped or spindle-shaped nuclei are met with at intervals of about 75 to 100 m. In cross-sections such degenerated fibres present the appearance of a very small tube filled with a homogeneous substance. They are separated in the funiculus by a small amount of fibrous connective tissue. Among the degenerated fibres a few somewhat larger fibres are met with which measure about 5 m. in diameter. These fibres consist of a delicate sheath filled with a homogeneous substance. Sections were stained after the Weigert hæmatoxylin method as modified by Benda, in order to determine whether these larger fibres possessed a medullary sheath. In none of the sections made were medullary fibres found. Neither was I able to make out with any degree of certainty an axis-cylinder in any of the larger or smaller fibres. In qualification of the above statements it should be stated that as these tissues were hardened in alcohol, and not in one of the chrome salts, it is very probable that neither the Weigert method nor the special methods for staining the axis-cylinder were of any value in determining whether a medullary sheath was present or absent in the nerves examined. Negative results where these methods cannot be followed are of very little value. Mention may be made of the appearances of a number of Pacinian bodies seen in the sections. These nerve-endings were normal in structure except that no nerve-fibres could be made out in the core.

While it is not within the scope of this paper to discuss exhaustively the different views which have been advanced in explanation of the process of regeneration of peripheral nerves, in order to interpret intelligently the various phenomena presented by the case under consideration, it will be necessary to state briefly the main theories entertained regarding the manner of the regeneration of a divided nerve. I would refer those desiring a more exhaustive discussion of the subject to a recent article by Kennedy,[1] whose bibliography is quite complete.

In the article referred to, Kennedy divides the views of the histologic process of regeneration into two groups:

1. The view established by Ranvier,[2,3] and closely coinciding with that of Waller, that the peripheral segment of the nerve takes no part in the process of regeneration, but that the latter is effected entirely by growth of the new axis-cylinders from those of the central end of the nerve, the peripheral segment acting merely as a guide or growth to the end-organs. This view is widely accepted, and is supported by the histogenetic researches of Kölliker[4] and His.[5,6,7] It has been recently supported by Howell and Huber,[8] Stroebe[9] and Notthafft,[10] who, however, find that the envelopes of the axis-cylinders are supplied from elements in the peripheral segment.

2. The view that the new fibres are derived from elements in the distal segment, and that the young fibres thus formed become attached

to the fibres of the central end, and thus restore conductivity. Recently Bunger " has adopted this view, and holds that the young fibres are derived from the protoplasm and nuclei of the interannular segments. These form spindle-cells which unite end to end and form protoplasmic threads, which soon show longitudinal striation, the beginning of the axis-cylinder. The new myelin sheath is formed from the outer layer of the young fibres and also partially by absorption of the old myelin. The old sheath of Schwann disappears and the new is derived from the endoneurial tissue. The nuclei of the new sheath of Schwann are the direct descendants of the nuclei of the old, and have clearly the value of neuroblasts. This view coincides with the histogenetic researches of Balfour[12] [13] and Milnes Marshall." [14]

According to the first view, every nerve-trunk, when divided, undergoes certain characteristic degenerative changes, consisting of segmentation of the myelin and axis-cylinder, a proliferation by means of a mitotic cell division of the interannular nuclei and the protoplasm surrounding these nuclei. Concurrent with the segmentation of myelin and axis-cylinder there goes on an absorption of the resulting fragments. As a result of these changes there remain only the collapsed sheaths of Schwann, containing a narrow band of nucleated protoplasm. These degenerative changes occur in the entire portion of every divided nerve-trunk, no matter how quickly or how accurately the divided ends are coapted.

The peripheral end of the central portion of the divided nerve undergoes the same degenerative changes to the extent of about ½ to 1½ cm., depending somewhat on the nature of the injury. Following immediately on these degenerative changes, regenerative changes begin to make their appearance. This regeneration of the divided nerve takes place from the central undegenerated end as outgrowths from the undegenerated young axis-cylinders. If the mechanical conditions be favorable, the peripheral degenerated portion of the nerve is subject to regeneration. In case the injured nerve is sutured soon after severance of its continuity, or when, from the nature and position of the injury, the ends of the divided nerve do not contract much, embryonic connective tissue developing between the severed ends forms only a relatively unimportant layer through which the down-growing axis-cylinder may penetrate and finally reach the degenerated distal nerve-trunk. If the embryonic connective tissue be for any reason denser, the small bundles of down-growing axis-cylinders meet with resistance in their attempt to reach the peripheral end of the divided nerve, become tortuous and deflected upon themselves, and the so-called bulb-tissue is formed.

Transplantation of a peripheral nerve between the ends of a divided nerve is a surgical attempt to prevent the formation of dense connective tissue and to provide a path of least resistance for the down-growing

young axis-cylinders. The microscopical researches of Huber[15] tend to prove that a transplanted nerve is superior to catgut strands (Assaky[16]) or tubular sutures (Vanlair[17]) as a path for the down-growth of the axis-cylinders.

Necessarily these conclusions were arrived at from entirely experimental studies. Whether they will apply as well to the human subject can be determined only by a careful study of a considerable number of cases of nerve transplantation. From the favorable result obtained in the present case, and from a consideration of nineteen additional cases of nerve transplantation I have been able to collect, I believe that the operation has a distinct place in surgery.

A consideration of the changes in sensation and motion following the operation in the case just reported reveals many interesting phenomena. The first return of sensation in a previously anæsthetic area was noted within twenty-four hours after the operation, sensation being tested on the thumb by a pin. Tests made in this way are not open to the objection of those made with a blunt object, for by the latter method, as pointed out by Létiévant,[18] impact against the anæsthetic area may be carried to sound papillæ and carried upward by other nerves. This rapid return of sensation is not an uncommon occurrence, as recorded cases of nerve section and suture reveal. As it is generally conceded that the transplanted nerve segment degenerates, as does any other resected nerve, only more rapidly, it is contrary to all biologic law to suppose that sensation is so quickly conveyed over this bridge of foreign tissue. Yet this rapid return of sensation is advanced as an argument by those who claim that the fibres originate in the peripheral end from the sheath of Schwann. Thus Kennedy,[1] in speaking of the rapid return of sensation after operation, says:

"Cases in which sensation remains totally lost before operation and long after date of section of the nerve, but returns in a few days after the operation, cannot be explained on the theories mentioned (slow process of regeneration from the central end), and must indicate a reunion of the nerve and re-establishment of conductivity."

That there is fallacy in this reasoning is seen by such cases as the one reported by Vucetic,[19] in which there was great improvement in sensation and some in motility six hours after 15½ cm. of the right median nerve were excised and the resected ends not brought together. There certainly was no question of the re-establishment of conductivity in this case; yet the sensation returned in the previously anæsthetic area. These facts would lead us to suppose that Vanlair[17] and others are right when they contend that rapid return of sensation after nerve section or a secondary operation must be due to anastomosing nerve-fibres or to supplementary supply. It is probably not true that a single area of skin is supplied by one nerve alone. A number of facts would

tend to show that there is a rich microscopical collateral nerve-supply which, under normal conditions, is not called into action, but under other conditions may alone be the carriers of sensation. The case of Richet,[20] where there was entire division of the median and no loss of sensation in its territory, and that of Létiévant,[18] who found, a month after the injury, no loss of sensation following division of the median and ulnar, show that the accepted distinction of motor and sensory nerves is not always constant. Weir Mitchell[21] has recorded a number of similar cases, among them the remarkable case of Nott, "who removed a large cyst from the flexor surface of the forearm, and with this tumor five inches of the median nerve, and yet the function usually assigned to this nerve was not interfered with in the slightest degree."

If, then, there be nerve-tracts to a given area other than those whose conductivity has been destroyed, why do not these tracts functionate at the time of the nerve section? It would seem as if irritation of the nerve at the point of lesion, and its consequent inhibitory action through the agency of the spinal cord on other peripheral nerve-fibres, must play an important causative part in the production of the phenomena. Experimentally, this inhibitory action of an irritated nerve has been shown to exist. Hence it seems perfectly plausible that the same effect may be produced by an injury to a peripheral nerve. This irritative inhibitory influence will continue in most cases, and distinct anæsthetic areas will be the result. The irritation being relieved by operation and the inhibitory influence removed, sensation conveyed through other tracts is the immediate result. In some such way as this must the early return of sensation be explained.

A study of Figs. 3 to 8 shows that from October 17th to November 8th, a period of twenty-two days, the return of sensation was relatively more rapid on the dorsal surface of the hand and in the neighborhood of parts supplied by the radial. On the palmar surface it will be seen that the return is much greater on the outer side of the hand in close proximity to fibres of the radial than on the ulnar side. This period—twenty-two days—is evidently too short for return of sensation from the down-growth of axis-cylinders, and must be explained by transmission of sensation through other tracts, the inhibitory influences of the irritated central nerve-ends having been removed by the operation. In the next period, however, from November 8th to November 29th, twenty-one days, we see a relatively greater progress in sensation on the ulnar side of the palmar surface of the hand. This may be due partially to the down-growth of axis-cylinders and partially to collateral nerve-supply. How much is to be ascribed to each it is impossible to say. The increase of sensation on the dorsal surface of the hand during this period is very slight, and the axis-cylinders

evidently have not reached the anæsthetic areas in their downward growth.

In the third period—November 29th to December 31st, thirty-two days—the progress of sensation on both palmar and dorsal surfaces has been relatively much slower than during the first two periods. This corresponds with the facts noted in other cases I have critically reviewed.

It is very graphically shown by the charts that the improvement in sensation is toward the finger-tips, and it may be noted in passing that this is an argument in favor of regeneration from the central and not the peripheral end. If regeneration of the axis-cylinders arises from the sheath of Schwann, and maturation of the fibres is completed when the central and peripheral ends are united, the new fibre should functionate throughout its entire length at the same time, which is not the case.

Particular attention is called to variations in sensation occurring during very short periods of time. For example, it is noted on November 8th that a previously sensory area in the palm was on that date anæsthetic. A number of other instances can be found by carefully comparing the notes with the charts. The explanation of this "vacillating sensation" may lie in the changes in nutrition occurring in the cells surrounding the nerve-endings. This has been shown repeatedly in physiological experiments where changes of nutrition in a muscle will produce the greatest variabilities in sensation. For the same reasons variations in muscular power may be expected, and while none were noted in the present case, Dr. Ferguson informs me that variations in the motor power were very marked in his case of nerve transplantation.

While the nutrition of the hand improved rapidly after the operation, it was by no means normal at the time the patient left this country to resume his work in Canada, and the freezing of the hand and subsequent amputation of two fingers were the result. This was unfortunate, as undoubteldy he eventually would have recovered sensation in the entire hand.

The improvement in motility is also very interesting. The saw cut, it will be remembered, was just above the wrist and below the muscular branches of the median, given off to all the long flexors of the forearm, except the flexor carpi ulnaris and half the flexor profundus digitorum, which are supplied by the ulnar. Hence the motor supply to these muscles was not interfered with, although the movements were not free, owing to the injury to the flexor tendons. The actions of the extensor muscles were not interfered with. There was complete paralysis of the small muscles of the hand supplied by the median and ulnar nerves.

The first improvement in motion is noted as occurring between two

and three weeks after the operation. At this time the patient was able to hold a tin wash-basin between the thumb and forefinger, although before operation it had been impossible to hold a lead-pencil between the same fingers. Opposition and adduction of the thumb is also noted as improving. This improvement in motion is more than can be explained by the freeing of the flexor tendons from adhesions at the time of the operation All the small muscles of the hand being paralyzed by the section of both ulnar and median nerves, the improvement in motion cannot be explained by vicarious movements of neighboring muscles which have not lost their nerve-supply (Létiévant[22]). The two possible exceptions to this might be the long flexor of the thumb and the extensor metacarpi pollicis. The latter muscle is innervated by the posterior interosseous, and therefore was uninjured in the present case. Its action is to carry the thumb outward and backward from the palm of the hand, and hence it is often called the abductor longus pollicis. But abduction of the thumb is not noted as improving at this time, although opposition and adduction are. Both these motions may be explained in part by the increased action of the long flexor of the thumb after the operation.

Unfortunately, careful electrical examination was not possible after the operation. When the first improvement in motion was noted the muscles failed to respond to faradic stimulation, the action of the galvanic current not being tried.

Two months after the operation the muscular power of the hand had markedly increased. The ends of the fingers could be flexed into the palm and an object be grasped through flexion of the knuckles. This motion is through the action of the interossei combined with the long flexors. Opposition of the thumb had increased markedly as had adduction, although the latter movement was still impossible without flexion of the thumb, and may in a large part have been due to the action of the long flexor. The atrophy of the small muscles is noted as diminishing, though still quite marked. The improvement of motor power in the whole hand was most marked, and in another month the patient declared it as well as ever, and went back to work. While this may have been true from the patient's stand-point, from a scientific point of view it was far from true; for over one year afterward the finer movements of the small muscles of the hand, such as abduction and adduction of the fingers (interossei) and adduction and abduction of the thumb without its flexion, are still impossible. There is also wasting of the smaller muscles of the hand. This shows that the action of the hand, as a whole, cannot be taken as a test of return of motility to individual formerly paralyzed muscles. As suggested by Kennedy, after five months' separation from their trophic centres the muscles may never

be able to resume their normal functions, although the regeneration of the nerves down to the muscles may be complete. It must also be borne in mind that owing to the frostbite the patient was unable to use his hand for over eight months, and this probably had a marked effect in preventing the already atrophied muscles resuming their normal size and function.

After a careful search I have been able to add seven cases of nerve transplantation to the thirteen collected by Huber.[15] Two of them (18 and 19) are unpublished cases, the notes of which were kindly furnished me by Drs. White and Ferguson. Huber collected in all fourteen cases; but his fourth case by Tillmanns must be rejected, as it was one of flap suture instead of transplantation. How the error arose seems to be uncertain, but the quotation from Bowlby[23] possibly explains where it originated. Neither in Tillmanns's communication to the German Surgical Society, April 11, 1885 (*Berliner klin. Wochenschrift*, 1885, p. 375), nor in his article on the subject of loss of nerve-substance in Langenbeck's *Archiv*, 1885, vol. xxxii., where it was reported in detail, is anything said about nerve transplantation in this case.

As showing the ease with which errors may arise in collecting cases from the literature, it is only necessary to mention the one discovered in going through the eleven cases of nerve transplantation mentioned by Spijarny.[24] This author reports among his eleven cases three by Albert. This must be reduced to two, as it is evident that the first and second refer to the same operation. Spijarny's quotation is evidently taken from Wolberg[25] in the first case, the latter publishing in full and giving the proper date, 1876. Albert's[26] one publication of the same operation furnishes the second one as given by Spijarny. That this is so is also sufficiently evident from the fact that Albert, communicating with Wolberg, would not have omitted it in his statistics.

Probably there are other cases of nerve transplantation buried in society reports, but as far as lay in my power I have endeavored to make the list complete. By private communications I was enabled to obtain later reports in Lange's and Bradley's cases. The number of cases is few and the value of a summary correspondingly small, but I believe it will be useful even if it be only to call attention to the lack of details characteristic of most of the cases.

TABULATED LIST OF 20 CASES OF PERIPHERAL NERVE TRANSPLANTATION.

No.	Operator and where reported.	Nerve operated upon and nature of injury.	Primary or secondary operation.	Distance separating central and peripheral segments.	Method used to overcome the nerve defect.	Results.
1	Albert Einige Operationen an Nerven. Wiener med. Presse, No. 39 und 41, 1885, Jahrgang 26.	Man, aged 40. Right median in forearm; result of removing sarcoma of the nerve. Had previously had fairly good results from paraneurotic catgut suture, but tumor reappeared, and this was second operation.	Primary.	3 ctm.	Implantation of a nerve obtained from an amputat'd foot; catgut suture above and below.	Patient observed ten days; wound bealed; no further observation; no results as regards sensibility and motility.
2	Albert. Ibid.	Farmer, aged 61. Had enlargements on several nerves, which were supposed to be of sarcomatous nature. June 11, 1881, one of these was removed from rigbt ulnar near elbow.	Primary.	10 ctm.	Implanted 10 ctm. from post. tibial taken from an amputated leg. Sutured witb catgut.	June 17, 1881. Tbe implanted segment came away in a necrotic state.
3	Kaufmann. Eine Nerven-Transplantation. Corresp. Blatt f. Schweizer Aerzte, Marcb 15, 1882. Revue des Sciences Médicales 1884, T. 24, p. 305.	Musculo-spiral nerve was sectioned during operation on necrosed humerus; tbe nerve was later exposed, the ends vivified. Owing to anchylosis the ends could not be brought togetber. Typical musculo-spiral paralysis.	Secondary.	4 ctm.	Dog's sciatic implanted; silk suture used.	Operation was followed by fever; tbe result could not be determined at tbe time the report was given; no further observation made.
4	F. Lange. Verbandl. d. deutsch Gesellsch. f. Chir., Berl., 1882, xi p. 55.	Musculo-spiral. Four inches of nerve removed in operation for neuroma, from where it leaves axilla to wbere it turns bebind humerus.	Primary.	4 inches.	Four incbes of dog's sciatic inserted between resected ends of nerve.	Wound healed; results negative as to function. In private communication, dated April 14, 1898, Dr. Lange writes: "Paralysis remained permanent; about one year after the operation I saw the patient again with an eruption of multiple neuromata, and I have no doubt that he eventually must have succumbed to the disease, wbich showed an unmistakably malignant cbaracter."
5	Gersung. Rep. by Damar Harrison. Trans. Clin. Soc. London, 1892, vol. xxv.	Median. Removal of neuroma just above annular ligament.	Primary.	6 ctm	Six ctm. of the sciatic removed from a rabbit engrafted.	Sensation began to return in two months; return of muscular movement not recorded; no further tendency to neuromatous degeneration; had before repeatedly suffered from this.
6	Vogt. Mittheilungen aus der Chir. klin. z. Griefswald, Urban u. Schwarzenbnrg, Wien, Liepzig, p. 122.	Musculo-spiral in upper arm. Gunshot wound.	Secondary, 1¼ years after injury.	8–10 ctm.	The defect was bridged by 12 ctm. taken from the two sciatics of a dog.	Suppuration followed; two months after tbe operation the nerve did not conduct impulses.

7	Mr Mayo Robson, Clinical Society of London, Friday, June 5, 1889. Brit. Med. Journ., 1889, vol. i. p. 244.	Girl, aged 14. Median, right side just above annular ligament. Patient had a tumor just above annular ligament; this was easily separated from the surrounding cellular tissue, but was inseparably blended with a cord to which it was attached. The cord was severed and tumor removed. After recovering from anæsthetic, patient had complete anæsthesia of the portion of hand supplied by median. Microscopical examination proved the cord to be composed of nerve fibres.	Secondary, 48 hours after operation.	2½ inches.	Implantation of a post. tibial nerve which had been removed from a leg amputated by Mr. Ward. The nerve was carried from one amphitheatre to another in warm carbolic acid solution; a segment of suitable length was taken and placed between the ends of the resected median, and sutured above and below by a direct catgut suture.	Thirty-six hours after the implantation, sensation had returned to the extent that touch with a pencil could be localized. Five weeks later the sensation was so perfect that the slightest touch could be localized. At this time there was manifest diminution of the abductor and flexor brevis pollicis; however, they were not completely paralyzed.
8	Dr. H. Landerer. Einheilung eines Kaninchen Nerven in einen Defect des Nerven Radialis. Deutsche Zeitschrift für Chirurgie, 1888, vol. xxviii. p. 604.	Woman, aged 18. Musculo-spiral nerve. Patient had acute phlegmon of upper arm 1½ years before this operation; ¾ of a year after the beginning of the disease, several sequestra were taken out, the fistula united by incision, and no doubt a segment of the radial removed. Total musculo-spiral paralysis.	Secondary, more than ½ year after removal of sequestra nerve was exposed.	3½ ctm.	Implantation of rabbit's sciatic; piece 4½ ctm. in length placed between the ends of radial, not sutured to the nerve, but held in place with several buried catgut sutures.	Wound healed by first intention; three weeks after implantation electrical stimulation above and below gave contraction of muscles; methodical electrical treatment was now begun; ten weeks after operation the patient was shown to the Leipzig Medical Association, and at that time could elevate the hand to the horizontal position even against some pressure. Landerer adds: "Diese Thatsachen scheinen mir eine andere Deutung kaum zuzulassen, als dass in der That das fremde Schaltstück wenigstens f. einige Zeit erhalten blieb und nervöse Erregungen zu leiten vermochte. Später wird es natürlich von eigenen Nerven-Fasern durchbrocken."
9	Mr. Ward. Remarks on Nerve Grafting. By Edw. Atkinson. Brit. Medical Journal, Sept. 13, 1890, vol. ii. p. 624.	Laborer, aged 42. Median nerve. July, 1888, patient was operated upon for painful tumor just above internal condyle of right arm. On cutting down, tumor was found to be surrounded by median, out of which it could easily be shelled. Nov. 1888, patient returned with similar growth in the same location. Jan. 1, 1889, this with 1¾ in. of the nerve was removed. Paresis of hand and forearm, intention tremor, darting pain before operation.	Primary.	1¾ inches.	2½ inches of a median nerve taken from an amputated arm were implanted and sutured with fine catgut.	Jan. 12. Numbness and tingling over the whole limb. Jan. 20. Wound healed. Feb. 2. Slight thickening along the course of the nerve; no pains; stated that fingers are cold, but feel warm: thumb and index finger very weak; hand looks wasted, especially the thenar muscles. July 26, 1890. Slight degree of wasting of the forearm; thenar eminence almost entirely absent; sensation normal to wrist: below, dull over the median area; movement of index and middle fingers normal in range, though weak; movements of the thumb limited to flexion, extension, and abduction; adduction and opposition entirely wanting.

No.	Operator and where reported.	Nerve operated upon and nature of injury.	Primary or secondary operation.	Distance separating central and peripheral segments.	Method used to overcome the nerve defect.	Results.
10	Mr. Mayo Robson. Remarks on Nerve Grafting. By Edw. Atkinson. British Medical Journal, Sept. 13, 1890, vol. ii. p. 624. Later report Brit. Med. Journ., Oct. 31, 1896.	Ulnar and median. Silk dresser, aged 29. 7 months before seen, patient fell on a scythe and received a deep cut on inner and lower part of right arm. At the time of admittance there was loss of sensation and motion in parts below injury supplied by median and ulnar.	Secondary, about 7 months after injury, Jan. 30, 1890.	Ends of median 2 inches apart after vivifying stump.	Ulnar nerve was sutured; internal cutaneous (?) was also found divid'd, and was sutured to the ulnar; 2 in. of the spinal cord of a rabbit implanted between the ends of median, and held in place by sutures.	Feb. 7. Patient can feel the scratch of a pin on flexor aspect of first phalanx of thumb, also at the root of index finger; can also tell when a hair located on the first phalanges of little and ring fingers is pulled, but cannot feel the scratch of a pin in these regions. March 4. Sensation in the palmar surface of hand supplied by median, and creeping along the fingers. No marked improvement in ulnar region. Apr. 1. Flexors of forearm all respond to kathodic closing current; muscles of the thenar eminence do not react on faradization. April 30. Sensation returning on the back of ring finger; voluntary flexion of wrist and fingers beginning to be possible. June 13. Nutrition of hand much improved; patient can pick up small objects; no sensation in area supplied by ulnar. Later report, March, 1891, resumed work. Exam. Feb. 1896. Left arm only $\frac{1}{8}$ in. larger than right; muscles completely restored, movements almost as perfect in right as in left arm; only weak muscle was adductor of thumb which had no perceptible power; sensation completely restored.
11	Edward Atkinson. Ibid.	Sciatic nerve. During operation for gluteal abscess 1 inch of the sciatic was removed.	Primary.	1 inch.	Immediately the exsected portion of the sciatic was again implanted and sutured in place with catgut sutures.	Complete anæsthesia of the limb the day after the operation; five days later sensation began to return to the toes; sixteen days after the operation the child could localize the touch of a pin-point anywhere on the limb.
12	Edward Atkinson. Loc. cit.	Miner, aged 22. Ulnar nerve. Laceration wound of right forearm. Ulnar artery and nerve, flex. sub. dig., flex. carp. ul., and palmaris long. were torn. Ends of ulnar free in the wound. Ulnar paralysis.	Primary.	2 inches.	$2\frac{1}{2}$ in. taken from the two sciatics of a rabbit implant'd and sutured with a single suture above and below to the ulnar; muscles sutured and wound closed.	Five days after the operation, on removing the dressing, the skin flap was under great strain; a stitch was removed, allowing the escape of a large quantity of a brownish, blood-stained pus; the wound was irrigated, and salicylic wool applied. Eighteen days. Sensation beginning to return in ring and little fingers. Twenty-five days. Wound closing; sensation increasing; some return of muscular power is noticed. July 24, three months after operation. Sensation complete in all fingers, except the last two phalanges of little finger; all fingers except little finger can be flexed on the palm.

13	Damar Harrison. A Case of Nerve Grafting. Transactions of Cliuical Society of London, 1892, vol. xxv.	Boy, aged 13. Median. Eleven weeks before admission a large glass plate fell on his wrist and divided all the tendons except flex. carp. ul., and the median nerve. At that time the structures were sutured; suppuration and sloughing ensuing. At the time of admission the hand was cold, skin glossy, aud muscles atrophied. Flexor tendons were matted together. There was loss of sensation and motion in the median area.	Secondary, 11 weeks.	2 inches.	2 in. were taken from the sciatic of a kitten and sutured between the ends of median with catgut; fingers were straightened and flexor teudons separated.	Wound healed by first intention; forty-eight hours after operation prick of pin could be felt in palm of hand and over the first phalanx of thumb. Three days, pricking felt over the thumb aud first phalaux of index and middle fingers; nutrition improved at the end of 2½ to 3 months. Eight months after operation he can abduct the thumb and oppose it to index finger; flexion of fingers on palm is not perfect.
14	Mitchell Banks. A brief report of the case is given by Damar Harrison, loc. cit.	Ulnar nerve. Excision of ueuromatous tumor.	Primary.	4 inches.	4 in. grafted from the sciatic of a dog.	Sensation is said to have returned at the end of thirty-six hours.
15	Moullin. Lancet, June 24, 1893.	Male. aged 28. Ununited fracture left humerus; good union of bone after operation, but motor and sensory paralysis. Section of musculo-spiral nerve removed.	Secondary.	2 inches.	2 in. of dog's sciatic implanted between resected ends of musculo-spiral, sutured with catgut.	Healed by first intention; sensation began to return in 3 days, and 5 days later was nearly normal in fingers; 15 days later only a very small region at metacarpo-phalangeal joint of index finger remained affected, and this soon disappeared; muscles reacted to strong faradic currents and seemed firmer, but voluntary power did not return, and wasting became extreme.
16	Heath. Lancet, 1893, vol. i. p. 1194.	Servant, aged 21. Right ulnar nerve. Gap of 2 inches left from excision of tumor; operation January 6, 1893: motor paralysis; auæsthesia of little and inner side of ring finger and back of haud to 3d metacarpal.	Secondary, 4 days after injury.	2½ inches.	Ends of excised nerves freshened and piece of posterior tibial of an amputated limb trausplanted; five silk sutures nsed	Decrease of anæsthesia of back of hand on 4th day. It had extended only to 3d metacarpal and now extended to 4th; no further return of sensation or power to muscles innervated by ulnar. Anæsthesia on palmar surface still existed to 4th metacarpal Operation Jan. 6, 1893; March 27 no return of function of ulnar; little finger blue and glossy, and small ulcer on dorsum.
17	Bradley. Medical News, Feb. 8, 1896; Lancet, 1896, vol. i. p. 1592.	Soldier. Musculo-spiral from fracture of right humerus. Paralysis of extensors; operat. June 22, 1895; nerve continuous, but involved at seat of injury in hard nodular tumor 2 ctm. long, 1 thick, nerve on each side for some distance firmly adherent to callus and dissected away with difficulty; tumor removed.	Secondary, 2 months after injury.	5 ctm.	5 ctm. of prepared sciatic of dog inserted in gap left by removal of tumor; catgut sutures.	About one month after operation ease passed from observation; thought there was some return in sensibility when last seen; no improvement 5 months after operation. Patient now in Soldiers' Home, Washington, D.C. The attending surgeon writes, uuder date of April 2, 1898: "Respectfully returned to the Gov. of the Home, with the report that —— has paralysis of the right hand and fingers. The nerve-grafting experiment was entirely unsuccessful."
18	J. William White. Unpublished data received from Dr. White in communication dated April 8, 1898. He was consulting surgeon, and did not have writteu uotes of case.	Female. Musculo-spiral nerve had been divided some time previously in removal of small tumor; operation showed ends considerably separated; nerve flap operation performed and ends united; no improvement followed. After another considerable delay second operat'n, uniting portions of nerve converted into a thin band of fibrous tissue; sections made and healthy uerve exposed above and below.	Secondary, considerable time after injury.	.....	Sciatic nerve of dog inserted in gap between resected ends of musculo-spiral; latter and dog nerve were thr'gh a small decalcified chicken bone intended to give stability to both.	Immediate result encouraging; no permanent improvement resulted.

No.	Operator and where reported.	Nerve operated upon and nature of injury.	Primary or secondary operation.	Distance separating central and peripheral segments.	Method used to overcome the nerve defect.	Results.
19	A. H. Ferguson. Unpublished.	Female, aged 18. During removal of neuroma of left median one inch of latter nerve removed just above wrist; gap bridged with catgut; in six weeks there was anæsthesia over area supplied by median. Grasp of hand imperfect. Three months after operation, Aug. 12, 1893, there was noticeable atrophy of the ball of the thumb; grasp about same; return of sensation not marked.	Secondary, Aug. 12, 1893. 3 months after catgut strands operation.	1⅓ inches.	1⅓ in. of sciatic nerve of young dog inserted between separated fragments of median; silk sutures used.	Improvement in sensation; third day after operation could locate fingers by pin pricks except third finger. On eighth day thumb and adjacent three fingers sensitive; ring finger hyperæsthetic; sensation around the nails was present Six weeks after the operation complained of painful, creeping sensation down fingers; sensation more normal; no return of motion. Was under direct observation for one year; improvement in motion began three months after operation; during year muscular power varied markedly during short intervals. Two years after operation (1895), "hand still lame, but very useful; sensation entirely returned for objects larger than fine thread or horse-hair."
20	Peterson.	Male, aged 24. May 17, 1896, sustained circular saw-cut of right wrist; median and ulnar nerves severed, also a number of flexor tendons; these were sutured; complete loss of sensation over areas supplied by median and ulnar nerves; blebs and ulcers appeared on fingers; fingers became flexed from contraction of tendons; marked atrophy of small muscles of hand and the thenar and hypothenar eminences flattened; hand could be partially closed; adduction and apposition of thumb impossible. Electrical examination showed reaction of degeneration in small muscles of hand. Operation Oct. 24, 1896, over five months after injury.	Secondary, 5 months after injury.	3½ ctm.	4 ctm. of sciatic nerves of a dog inserted between the incised ends of both median and ulnar nerves; fragments sutured with kangaroo tendon above and below.	Return of sensation to thumb 24 hours after operation. 7th day after operation. Superficial suppuration of median incision; sensory area on thumb increasing; pricking sensation of hand. 8th day, rapid increase of sensation over dorsal surface of hand. From 8th to 21st day, increasing sensory areas on dorsal and palmar surface of hand; trophic ulcers have disappeared; hand natural color. On 21st day decided improvement in muscular power; can touch dorsal surface of second knuckle of first finger with end of thumb, etc. Two months after operation tips of fingers can be closed into palms; grasp of hand good; less atrophy of small muscles of hand. 3 months. Went to work; said his hand was as good as ever; could chop wood, etc.; sensation complete except tips of 2d, 3d, and 4th fingers. 4 months. Froze his hand, unable to use it for eight months; discharge from 1st and 3d fingers necessitating amputation. 1½ years after operation. Hand used every day in his work; sensation very nearly normal; finer movement of hand still impossible; some atrophy of muscles.

SUMMARY OF TWENTY CASES OF NERVE TRANSPLANTATION.

Of the 20 cases, 9 were males and 5 females. The sex was unrecorded in 6. The age was stated in 12 cases, the average being twenty-seven and one-half years. The median nerve alone was operated upon in 7 cases, the ulnar alone in 3 cases, and the median and ulnar together in 2 cases. The musculo-spiral was operated upon in 7 cases, and the sciatic in 1 case.

The injuries to the nerves necessitating transplantation in 10 cases were due to removal of tumors involving the nerves. Incised wounds were responsible for 4 cases. Injury followed operation for necrosis twice, while gunshot-wound, operation for gluteal abscess, ununited fracture, and simple fracture were responsible for one case each.

There were 8 primary and 12 secondary operations. The time elapsing from date of injury to time of operation varied from forty-eight hours to one and one-quarter years. Eight out of the 12 cases of secondary operation, or two-thirds, showed improvement in sensation or motion, while only 4 out of the 8 cases of primary operation, or one-half, showed signs of improvement. However, 2 of the 8 cases (11 and 12) were observed only ten and six days respectively.

The distance separating the central and peripheral fragments varied from 3 to 10 cm. As far as can be judged, the distance did not seem to effect ultimate results. In 9 cases the transplanted segments were from sciatics of dogs, in 5 from recently amputated limbs, in 3 from the sciatics of rabbits, and 1 each from the spinal cord of a rabbit and the sciatic of a kitten. In one case the excised nerve was itself implanted.

In 9 cases catgut was used to unite transplanted segments to central and peripheral ends of excised nerves, in 3 silk, and once kangaroo tendon was employed. In 7 cases no mention is made of the suture material.

Strictly speaking, no case can be said to have recovered entirely, if by that be meant a complete restoration of sensation, together with a return of the muscles to their former size and power. The nearest approach to this condition occurs in the case longest under observation (10), where at the end of six years sensation had entirely returned, and the only remaining weak muscle was the abductor of the thumb. In 3 cases (10, 19, and 20) there was practical recovery of sensation and motion, so that the hand was entirely useful. In two of these (10 and 20) both median and ulnar nerves were operated upon.

There was complete return of sensation recorded in 4 cases (7, 10, 11, and 19). In 3 cases (12, 15, and 20) there was nearly complete return of sensation. Improvement in sensation was recorded in 4 cases

(5, 13, 14, and 16), while improvement in muscular power is noted also in 4 cases (7, 8, 12, and 13).

There was improvement in either muscular power or sensation in 12 cases (5, 7, 8, 10, 11, 12, 13, 14, 15, 16, 19, and 20), while in 6 cases (1, 4, 6, 9, 17, and 18) there was no improvement in either sensation or motion.

The shortest time any case was under observation was six days; the longest six years. Of the 5 cases under observation one year or more (4, 10, 17, 19, and 20), 3 (10, 19, and 20) made nearly complete recoveries in both sensation and motion.

The average time in which sensation first appeared after the operation was about 10 days, while the average time for the first appearance of motion was about 2½ months.

GENERAL CONCLUSIONS.

1. Transplantation of a peripheral nerve segment to bridge over a gap between the two ends of a resected nerve is a legitimate surgical procedure.

2. Under favorable conditions at least partial and at times complete restoration of sensation and motion may be expected to follow the operation.

3. Regeneration of the degenerated peripheral end is due to down-growths from the axis-cylinders of the central end.

4. From the slowness of this process the longer the time after operation the more favorable will be the results.

5. Sensation may return very early after operation, and, as a rule, precedes return of motion.

6. This rapid return of sensation is not due to down-growth of axis-cylinders or to conductivity of the transplanted fragment, but must be explained by collateral nerve-supply.

7. In many cases very early return of motion after transplantation may be due to vicarious movements of other muscles than those formerly paralyzed and not to a regeneration of the latter's nerve-supply.

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